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" Calibration of Large High Pressure V-Cone Flowmeters at High Reynolds Numbers in the CEESI Iowa Natural Gas Test Facility "

Authors:

Steve Caldwell – Vice President, CEESI
Tom Kegel – Director of Engineering, CEESI
Dr R.J.W.Peters – Flow Measurement Technology Manager, McCrometer

Synopsis: *The paper will describe the testing of 18"(457mm) to 28"(711mm) V-Cone Meters over a wide Reynolds Number range to determine the Discharge Coefficients. These results will be presented in graphical form.*
The tests were undertaken in the CEESI Iowa Natural Gas Test Facility and details of this laboratory are given in the paper. The calibration philosophy and the uncertainties achieved will be described. The measurement assurance program for this facility was used during these tests and this will be described.

1. Background

McCrometer received an order for 25 V-Cone meters for natural gas transmission. These meters ranged in size from 18"(457mm) to 28"(711mm) flange class 900lbs. The V-Cones meters require to be individually calibrated to guarantee an uncertainty of 0.5%. However, the customer did not require such an uncertainty and decided to take a sample from each line size. For one line size (26", 660mm) it was decided to select 2 meters, which were ostensibly the same, and determine the spread in results for the two meters.

To test large meters, 28"(711mm) in natural gas in the American continent restricted the choice of laboratory and it was decided to test the meters in the CEESI Iowa facility, which tests using natural gas.

As the laboratory is traceable to the USA National Standard this was acceptable to the international gas company.

This paper describes the Iowa facility, details of the meters tested, and the results achieved for the discharge coefficient over the flow range specified by the customer.

2. Iowa Test Facility

The Iowa calibration facility, designed primarily to accommodate large ultrasonic meters, has been operational since March 1999. The facility is located adjacent to a custody transfer meter station, which is on a 42" (1067 mm) pipeline operated by the Northern Border Pipeline Company. The basic layout is shown in Figure 1.

One 42” (1067 mm) pipeline enters the facility at A while three pipelines exit the facility at B, C, and D. The nominal diameters are 30” (762 mm) for B and D and 36” (914 mm) for the pipeline exiting at C. A flow regulating station (valves V_4, V_5, and V_6) is located within the facility on pipeline D. As part of their normal operation, Northern Border controls flow through pipelines B, C, and D.

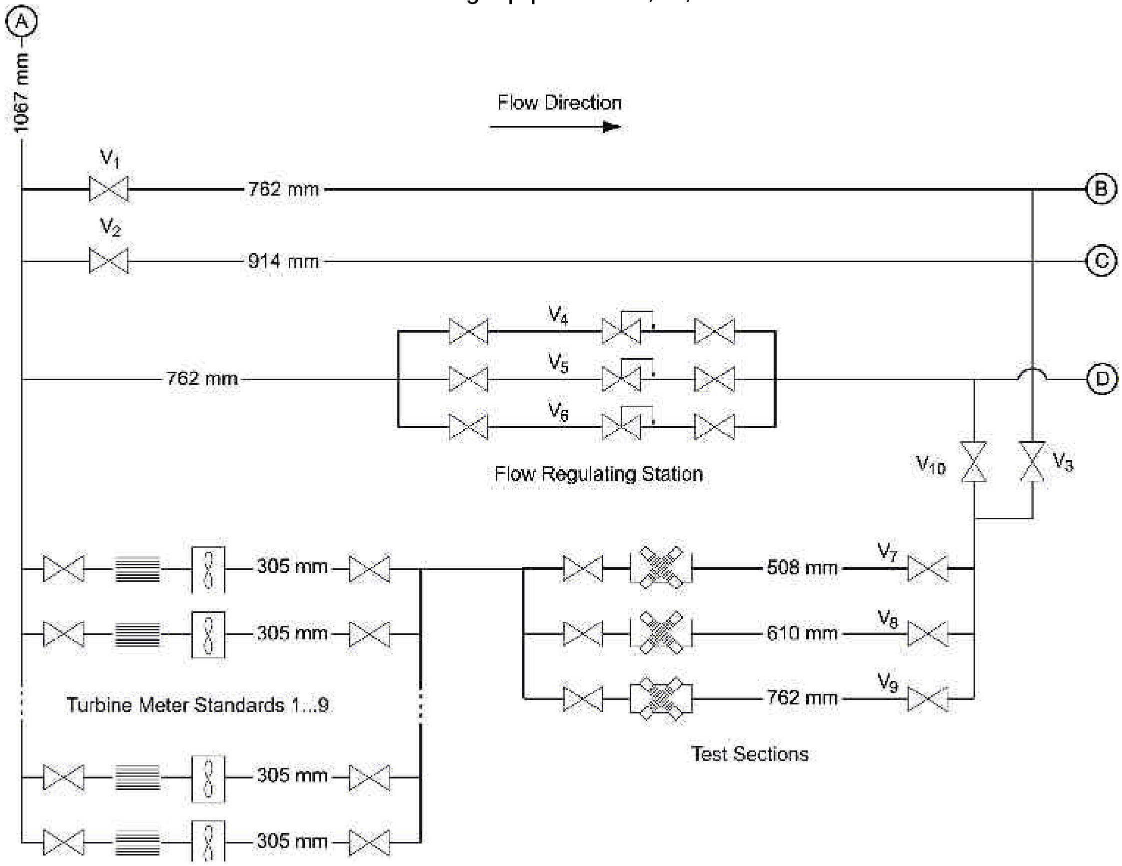

Fig 1 Iowa Test Facility

The gas that bypasses the pipeline flows through a parallel array of nine 12” (305 mm) turbine meters which serve as flow standards. Each turbine meter has been installed in accordance with the industry standard. One or more turbine meters are opened to achieve a particular flowrate, double block and bleed valves isolate those turbine meters not in use. Turbine meters are selected such that flowrate is always measured with the lowest possible uncertainty. Operating with all nine turbine meters at full capacity results in a test section flowrate of 22,500 ft^3/min (38,200 m^3/hr). The gas exits the turbine meter array and flows through one of three test sections. Three test sections allow for the calibration of a range of meter sizes and installation conditions. Each test section contains an ultrasonic flowmeter check standard that is part of the Measurement Assurance program described below. With normal pipeline operation the test section pressure is between 1000 and 1100 psia (6.9 and 7.6 MPa). A fourth, smaller test section is available for calibrating at very low flow rates. It is not discussed in the present paper.

For meters smaller than 16” (406 mm), the gas flowing through pipeline D is directed through the turbine meter standards and then into the test section. Valves V_1 and V_2 are open, valve V_3 is closed, while valve V_{10} is always open. For higher velocities through meters 16” (406 mm) or larger, the gas flowing through pipelines B, C, and D is directed through the test facility. Valves V_1 and V_2 are closed, valves V_3 and V_{10} are open. Primary flow control is achieved using valves V_4, V_5, and V_6. Secondary flow control, if required, is achieved using valves V_7, V_8, or V_9.

The turbine meters, check standards and test sections are provided with pressure and temperature measurements. A gas chromatograph is located on the gas pipeline as part of a custody transfer meter station. These measurements are used to calculate gas densities (using AGA 8) at the different meters. The volume flow through a meter under test is calculated from:

$$q_{V0} = \frac{1}{r_0} \sum r_i q_{Vi} \qquad \text{Eq. 1}$$

where:

q_{V0}: flowrate through meter under test
$?_0$: density at meter under test
q_{Vi}: flowrate through one turbine standard
$?_i$: density at one turbine standard

The performance of the pressure, temperature and composition measurements are monitored as part of the Measurement Assurance program described below.

3. Uncertainty Analysis

The uncertainty of the Iowa facility is detailed in Reference 1. That analysis resulted in an estimated uncertainty in test meter K Factor of ±0.23% at a 95% level of confidence. This value is made up of the following components:

3.1 Turbine array volumetric flowrate, u = ±1792 ppm = ±0.179%
3.2 Test meter K Factor, u = ±824 ppm = ±0.082%
3.3 Turbine array & test section temperature measurement, u = ±644 ppm = ±0.064% (each)
3.4 Turbine array & test section pressure measurement, u = ±556 ppm = ±0.056% (each)
3.5 Turbine array & test section state equation, u = ±58 ppm = ±0.006% (each)
3.6 Turbine array & test section gas composition, u = ±34 ppm = ±0.003% (each)

Each turbine meter was calibrated in the CEESI Colorado facility. Item 1 includes the uncertainty associated with this process as well as the random effects associated with the use of the turbine meters. Items 3-6 account for the determination of density values in Eq. 1.
The uncertainty components are highly correlated because the changes in pressure, temperature and composition between turbine array and test section are very small. The result of this correlation is to significantly reduce the uncertainty components identified as Items 3-6 above. Additional details are provided in Ref. 1.

Item 3.2 in the uncertainty analysis accounts for several effects present in a “typical” ultrasonic meter:

- 3.2.1 Hydrodynamic effects
- 3.2.2 Interaction between the flowing gas and ultrasonic signals
- 3.2.3 Data acquisition and processing.

This component is included in the analysis for two reasons. First, these effects are present in every set of calibration results and they are difficult to “remove” from the uncertainty analysis. Second, the uncertainty in meter K Factor is more valuable to the customer because it includes the performance of their meter.

4. Iowa Measurement Assurance Program

An extensive Measurement Assurance Program (MAP) has been implemented in the Iowa facility. There are two objectives in the CEESI Iowa MAP: The first objective is to assure that the measurement process is operating consistently. The second objective is to provide data for the uncertainty analysis. The MAP has been designed based on Reference 2 and it is described in Reference 3.

The main component of the MAP is the use of check standards. Each test section includes an ultrasonic meter check standard that is present during each calibration. Over time historical data have been accumulated on each check standard and typical performance has been quantified. At the conclusion of a customer calibration the consistent performance of the check standard provides assurance that the entire calibration process is also operating consistently. The formal tool used to monitor the check standards is the control chart, additional details are contained in Ref. 3.

While the check standards monitor the entire calibration, several programs are in place to monitor the individual components. The turbine substitution test identifies the performance of individual turbine meters relative to each other. The critical pressure and temperature measurements are made with redundant instruments. Control charts are used to monitor the transducer pair differences. Finally, the weekly calibration results for the gas chromatograph are monitored using control charts. Additional details are contained in Ref. 3.

5. Uncertainty of the Meters Tested

This section provides a brief summary of the uncertainty in the value of discharge coefficient. The Iowa facility uncertainty analysis, described above, needs to be modified slightly for the present test results. First, the “Test meter K Factor” needs to account for a V-Cone, instead of an ultrasonic meter. Second, additional uncertainty components are required to account for density and differential pressure.

The equation for volumetric flow through a V-Cone is:

$$q_v = \frac{p}{4}\frac{d^2 C_d Y}{\sqrt{1-b^4}}\sqrt{\frac{2\Delta P}{r}} \qquad \text{Eq. 2}$$

Solving for C_d:

$$C_d = \frac{4}{\pi}\frac{q_v\sqrt{1-\beta^4}}{d^2 Y}\sqrt{\frac{\rho}{2\Delta P}} \qquad \text{Eq. 3}$$

The variables that contribute uncertainty to discharge coefficient are q_v, ? and ?P. The variables d, ß and Y are assumed to contribute no uncertainty so long as consistent values are used. The uncertainty in q_v is u = 0.23% assuming the V-Cone performance is similar to that observed with ultrasonic meters. The similarity in performance is discussed below.

The uncertainty contributed by density and differential pressure are made up of the following components:

5.1 Differential pressure transducer, u = ±0.25%
5.2 Pressure transducer, u = ±0.25%
5.3 Temperature transducer, u = ±0.08%
5.4 Gas chromatograph, u = ±0.50%
5.5 AGA 8 equation of state, u = ±0.10%

The numerical values, determined from manufacturer's specifications, are stated at 95% levels of confidence.

The following sensitivity coefficient are applied when combining the uncertainty components[4]:

$$\frac{\partial C_d}{\partial \rho}\frac{\rho}{C_d} = 0.5, \quad \frac{\partial C_d}{\partial \Delta P}\frac{\Delta P}{C_d} = -0.5, \quad \text{and} \quad \frac{\partial C_d}{\partial q_v}\frac{q_v}{C_d} = 1.0$$

Combining all the uncertainty components results in the uncertainty in discharge coefficient of u = ± 0.39% (95% confidence).

6. Choice of V-Cone Meters for the Gas Transmission Line

The meters required for the Natural Gas Transmission lines were class 900 lb and the sizes were as follows:

Size	**No of Meters**
18"(457mm)	2
20"(508mm)	1
24"(610mm)	6
26"(660mm)	11
28"(711mm)	5

The Oil Company and the contracting firm wanted to meter the gas as economically as possible, both in terms of Capex and Opex. For a low Capex this demanded meters, which would be competitively priced but in addition the installation cost would be low. The V-Cone met this requirement as the cone conditions the flow and reduces the pressure loss. This means that short upstream lengths can be tolerated to achieve an acceptable uncertainty in measurement.

The Opex costs are also relatively low since with low-pressure drop the pumping costs are reduced. As he actual Secondary instrumentation consists of Temperature, Pressure and Differential Pressure transducers these can fall under the standard instrumentation Quality Control cycle.

The added value with the V-Cone, in this plant, is that it is very forgiving when the gas is wet. The liquid can flow along the pipe wall past the cone and there is no build up of liquid in the flow meter.

One major cost concern with the V-Cones was the requirement to have the meters, or at least a selection of them, flow calibrated. Although this would also be the case for Venturi, Ultrasonic and Turbine Gas Meters it would not be the case for orifice metering. This factor leads to the Testing Program discussed in Section 8.

7. Sizing the V-Cone Meters

Six of the Sizing Sheets are in the Appendix. These are the meters, which were flow tested at Iowa and are an example of all the 25 meters.

The customer wanted a 10:1 turn down ratio and a relatively high Re, with some meters as high as 9e+07. In addition there was a requirement for as low a head loss as possible. These requirements resulted in a beta ratio in many cases of 0.8, which for the V-Cone means that there is a relatively small cone and a large open area. For low uncertainty with the V-Cone this is the largest value one would want.

Fig 2 is a drawing of the 28” (711mm) V-cone meter, which was supplied. It will be noted that there are gussets welded onto the cone and this is always done on 8” (203mm) meters and larger. In addition McCrometer does a stress analysis for all their meters and for this particular contract the stress and vibrational analysis was also provided to the customer.

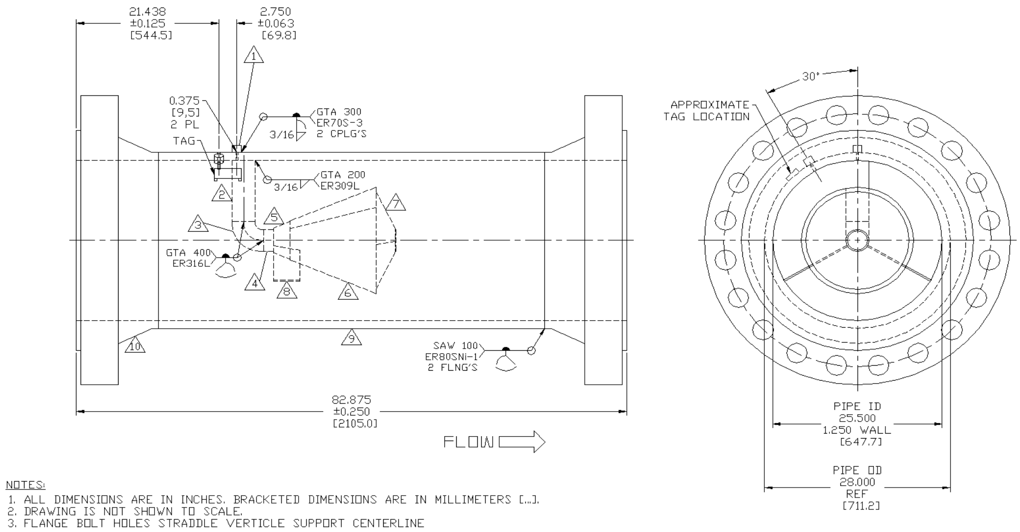

Fig 2 Drawing of the 28"(711mm) V-Cone Meter

8. Decision on which meters should be flow tested in Gas

The customer was not prepared to pay for the gas testing of every meter and accepted that there would be additional uncertainty in the C_d value for the meter, which were not tested. This could be as much as 3 to 5% due to manufacturing tolerances.

From the table of meters and the manufacturing of the meters it was apparent that as the meters are a similar size, testing of a sample should give an indication of the possible spread of results for the untested meters. The decision was taken to test the following meters:

Size	No of Meters	No of Meters Flow Tested
18"(457mm)	2	1
20"(508mm)	1	1
24"(610mm)	6	1
26"(660mm)	11	2
28"(711mm)	5	1

Apart from the fact that there are more 26"(660mm) meters, this size falls comfortably between the 24" (610mm)and the 28"(711mm) meters and strengthens the understanding of the C_d value achieved.
Duplicating the testing of this size gave a measure of the scatter in the results with 2 meters, which have been manufactured to the same requirements.

9. Graphs of the Discharge Coefficients (C_d) against Reynolds Number (Re) for the Flow Tests

Note: In the following graphs the dotted lines are at + / - 2 Standard Deviations (+ /- 2s)

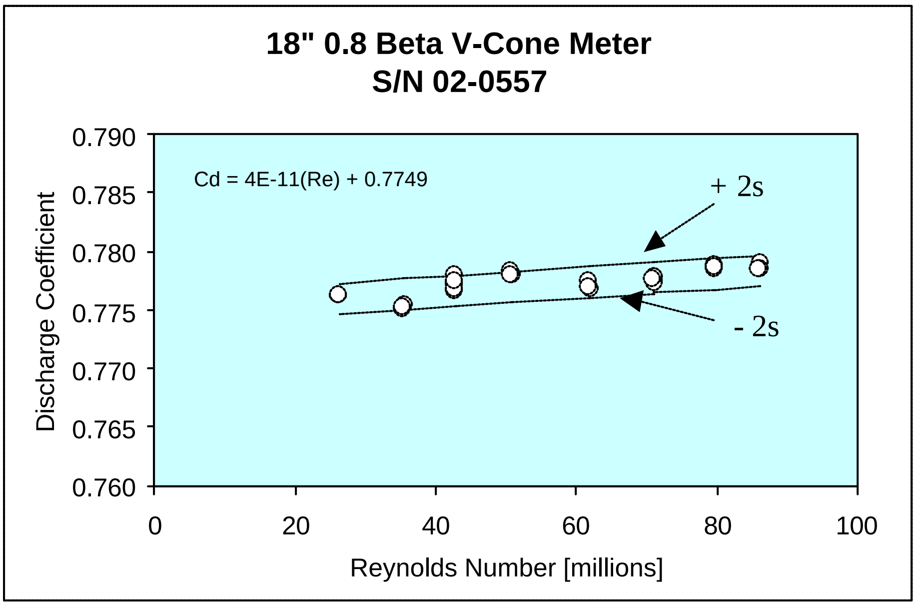

Fig 2 18"(457mm) Meter 02-0557

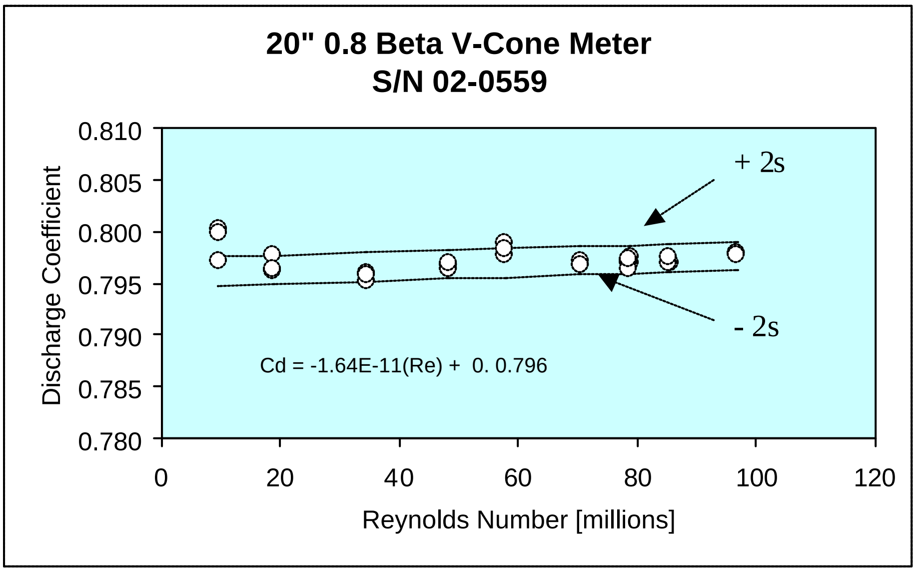

Fig 3 20"(508mm) Meter 02-0559

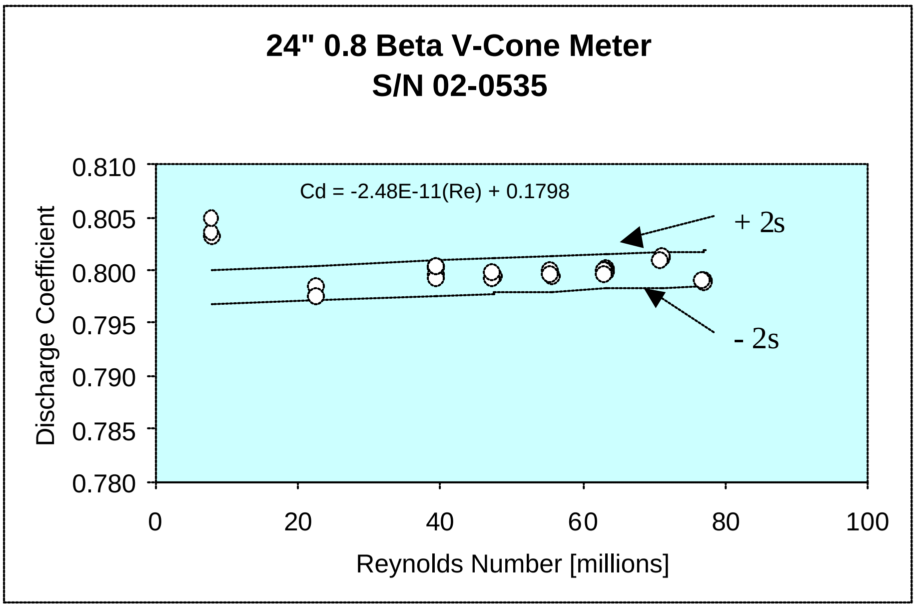

Fig 4 24"(610mm) Meter 02-0535

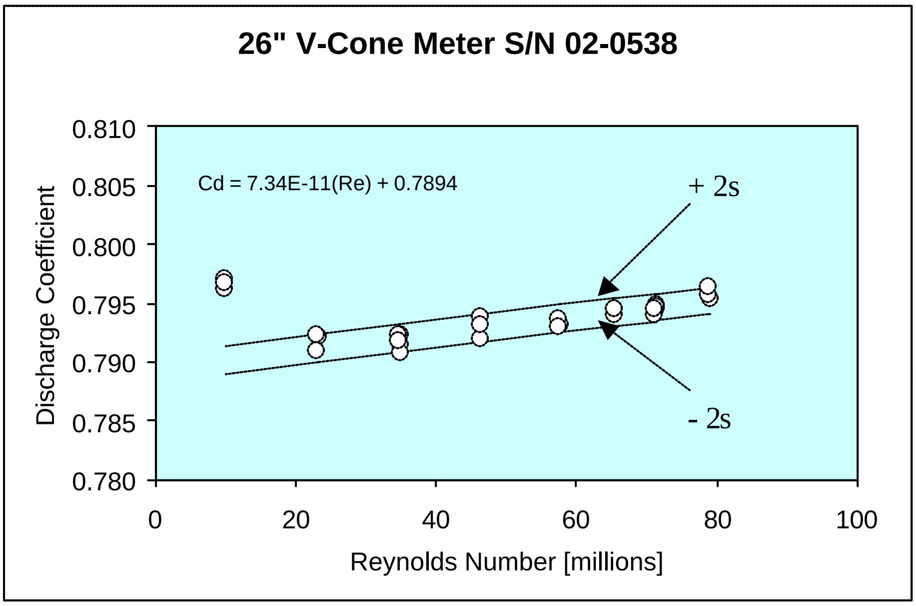

Fig 5 26”(660mm) Meter 02-0538

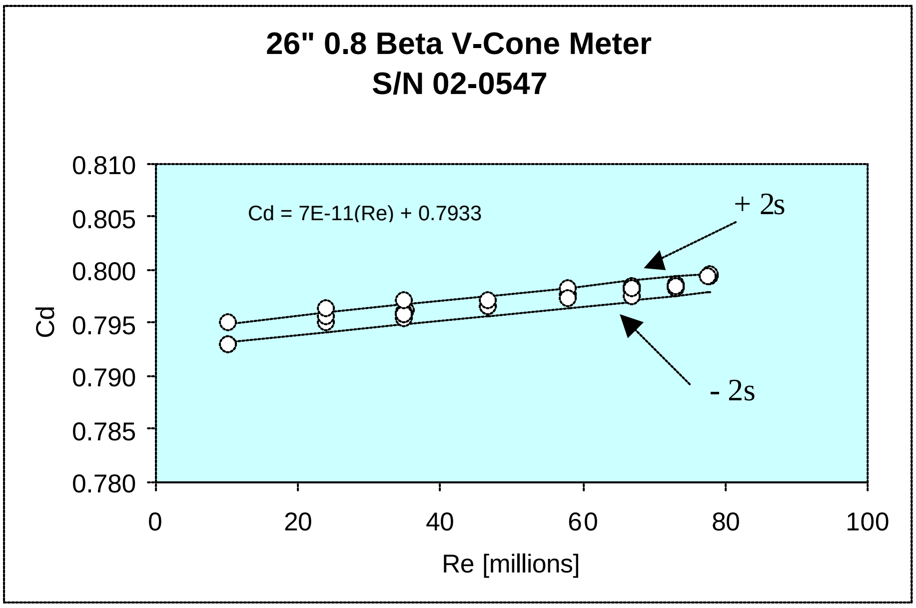

Fig 6 26” (660mm) Meter 02-0547

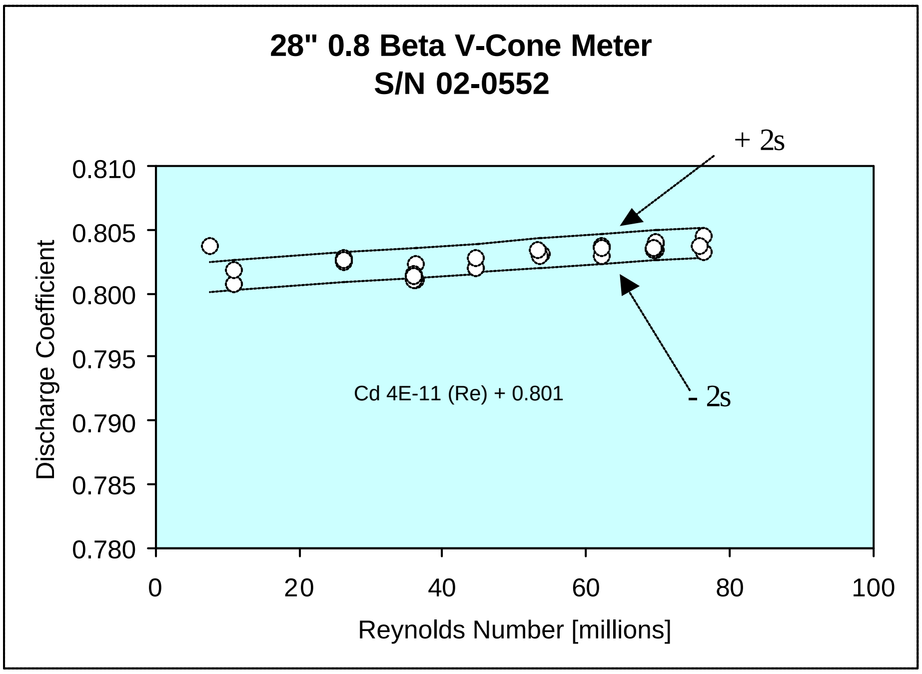

Fig 7 28"(711mm) Meter 02-0552

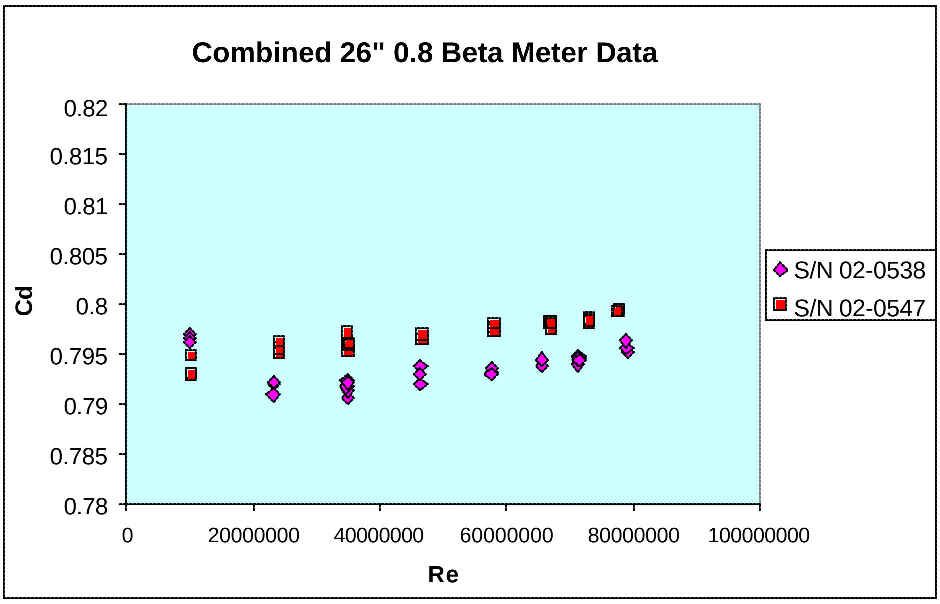

Fig 8 The two 26"(660mm) Meters plotted together

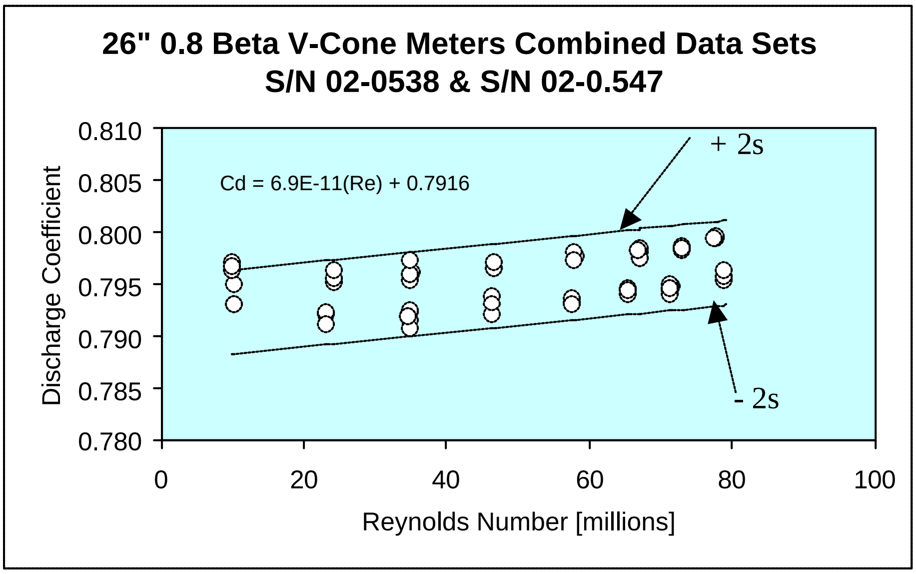

Fig 9 A common equation and error band for the two 26"(660mm) Meters

10. Table of Results from Iowa – using all the results

Size	Serial No	Ave. C_d	Total Spread	% Spread
18"(457mm)	02-0557	0.7773	0.00397	0.5107
20"(508mm)	02-0559	0.7972	0.00507	0.6356
24"(610mm)	02-0535	0.7999	0.00754	0.9425
26"(660mm)	02-0538	0.7937	0.00634	0.7988
26"(660mm)	02-0547	0.7778	0.00657	0.8446
28"(711mm)	02-0552	0.8026	0.00377	0.4697
All data 26"(660mm)		0.7920	0.00878	1.1085

11. Calibration Results

The calibration results are symbolized by open circles in Figures 2 to 9. The dotted lines represent 95% confidence intervals about the best fit straight lines. These intervals were calculated to contain 95% of the data points. For three of the meters (serial numbers 02-0535, 02-0538, and 02-0559) the slightly nonlinear low flow conditions were excluded from the analysis. The interval widths are tabulated below.

Size	S/N	Interval Width [%]
28”	02-0552	± 0.147
26”	02-0547	± 0.118
26”	02-0538	± 0.149

Size	S/N	Interval Width [%]
24”	02-0535	± 0.203
20”	02-0559	± 0.171
18”	02-0557	± 0.169

The three larger meters exhibit performance comparable to the typical ultrasonic meter. The interval width is less than or equal to ± 0.15%, the typical magnitude of scatter observed in an ultrasonic meter calibration. The three smaller meters exhibit a slightly larger degree of scatter.

The analysis above was performed for the data from the two 26” meters taken together. The results are contained in Figures 8 and 9, the confidence interval width is ± 0.512%.

When we consider the uncertainty of the laboratory it is clear that the V-Cone meters tested meet a level of uncertainty comparable or better than all other gas meters.

12. Equation used to estimate C_d value from a tested C_d value from a similar meter.

Using the Flow Equation for a V-Cone, under constant conditions it can be simplified to be:

$$C_d \propto \frac{K\sqrt{1-b^4}}{D^2 b^2}$$

From this equation a value for K for the meters, which were calibrated, can be derived. This value of K and the measured values of D and β can then be used to establish a C_d value for the untested meters

13. Conclusions

13.1 The CEESI Iowa Test Facility was an excellent laboratory for testing the large V-Cone meters over a wide flow range

13.2 The results of the individual V-Cone meter tests exceeded the expectation of the meter manufacturer and ranged from an uncertainty of +/- 0.118 % to +/- 0.203% for the individual meters.

13.3 Two “identical” 26”(660mm) meters were manufactured and tested and the total spread for all the test points was +/- 0.55%.

13.4 A simple test formula was presented to correct the C_d value for the meters, which were not tested.

References

1. Kegel, T. M., “Uncertainty Analysis of an Ultrasonic Meter Calibration Process,” *AGA Operations Conference*, Chicago, IL, May 2002.

2. Croarkin, Carroll, *Measurement Assurance Programs, Part 2: Development and Implementation*, NBS Special Publication 676-2, 1985.

3. Kegel, T. M., “Quality Control Program of the CEESI Ventura Calibration Facility,” 11th Flomeko, May 2003.

4. International Organization for Standardization, Guide to the Expression of Uncertainty in Measurement,
1995.

APPENDIX

Application sizing for all the Meters Tested

V-Cone Application Sizing

Serial #	02-0557	Fluid State	GAS
Tag	02-FE-911	Fluid	HC Gas
Model	VR18-01	End User	
Job Ref.	J89475		

Description	18" V-Cone, A672-B70 EFW Pipe, Sch 80, S316 Cone, A105 B16.5 900# WN RTJ Flg	Mktg. Code	3 8 030
Note			

C_f				q	max. Flowrate	1300000	Nm3/H		McCrometer Cal.	
P_f	102.7	kg/cm2A		Re	max. Reynolds	8.265e+07			Third Party Cal.	
T_f	65	°C		V	max. Velocity	102.2	fps		Dye. Pen. Exam.	
ρ	79.82	kg/m3		ΔP	max. Dp	8967.3	mmWC		Hydro. Test	
μ	1.200e-02	cP	=	ΔP	min. Dp	88.718	mmWC		X-Ray Exam.	
G	0.6760		=	D	Meter I.D.	404.95	mm		Mag. Part.	
Z	0.8920		=	d	Cone O.D.	240.21	mm		PMI	
Y	0.99401			β	Beta Ratio	0.8061			CMTR Copies	
k	1.524		=		Turn Down	10			McCrometer Eng.	CG
C_p										
Mw	19.58		=							
P_b	14.696	psiA								
T_b	491.67	°R								
Z_b	1.000									
P_{baro}	14.696	psiA								
P_c										
T_c										
F_a	1.001									
aPE	D 6.7e-06	d 6.7e-06								
P_v										
P_{loss}	3.745	psiA								

= Entered value

	Re	Velocity fps	Gas. Exp. Y	ΔP mmWC	Flowrate Nm3/H
1	8.265e+07	102.21	0.9946	8967.3	1.3000e+06
2	7.439e+07	91.987	0.9956	7248.2	1.1700e+06
3	6.612e+07	81.766	0.9966	5716.5	1.0400e+06
4	5.786e+07	71.546	0.9974	4369.6	9.1000e+05
5	4.959e+07	61.324	0.9981	3205.8	7.8000e+05
6	4.133e+07	51.104	0.9987	2223.6	6.5000e+05
7	3.306e+07	40.883	0.9991	1421.8	5.2000e+05
8	2.480e+07	30.662	0.9995	799.13	3.9000e+05
9	1.653e+07	20.441	0.9998	354.98	2.6000e+05
10	8.265e+06	10.221	1.0000	88.718	1.3000e+05

Table based on one flow condition (P, T, Z, k ...) V40 Version 1.23
Standard Gas Expansion Equation - Rev. Aug. 2001

Record Start Date	02-28-2002
Print Date	02-25-2003

McCROMETER

V-Cone Application Sizing

Serial #	02-0559	Fluid State	GAS
Tag	06-FE-911	Fluid	HC Gas
Model	VR20-02	End User	
Job Ref.	JB9475		

Description	20" V-Cone, A672-B70 EFW Pipe, Sch 80, S316 Cone, A105 B16.5 900# WN RTJ Flg	Mfdg. Code	3 5 030
Note			

C_f				q	max. Flowrate	1600000	Nm3/H	McCrometer Cal.	
P_f	103.7	kg/cm2A		Re	max. Reynolds	9.113e+07		Third Party Cal.	
T_f	65	°C		V	max. Velocity	98.73	fps	Dye. Pen. Exam.	
ρ	79.96	kg/m3		ΔP	max. Dp	8312.6	mmWC	Hydro. Test	
μ	1.200e-02	cP	⇐	ΔP	min. Dp	82.320	mmWC	X-Ray Exam.	
G	0.6795		⇐	D	Meter I.D.	454.38	mm	Mag. Part.	
Z	0.8500		⇐	d	Cone O.D.	271.53	mm	PMI	
Y	0.99508			β	Beta Ratio	0.8018		CMTR Copies	
k	1.527		⇐		Turn Down	10		McCrometer Eng.	CG
C_p									
Mw	19.68		⇐						
P_b	14.696	psiA							
T_b	491.67	°R							
Z_b	1.000								
P_{baro}	14.696	psiA							
P_o									
T_o									
F_a	1.001								
aPE	D 6.7e-06	d 6.7e-06							
P_v									
P_{loss}	3.520	psiA							

⇐ Entered value.

	Re	Velocity fps	Gas. Exp. Y	ΔP mmWC	Flowrate Nm3/H
1	9.113e+07	98.729	0.9951	8312.6	1.6000e+06
2	8.202e+07	88.856	0.9960	6720.8	1.4400e+06
3	7.291e+07	78.983	0.9969	5301.0	1.2800e+06
4	6.379e+07	69.110	0.9976	4052.7	1.1200e+06
5	5.468e+07	59.237	0.9982	2973.7	9.6000e+05
6	4.557e+07	49.364	0.9988	2062.8	8.0000e+05
7	3.645e+07	39.491	0.9992	1319.0	6.4000e+05
8	2.734e+07	29.619	0.9996	741.47	4.8000e+05
9	1.823e+07	19.746	0.9998	329.37	3.2000e+05
10	9.113e+06	9.8729	1.0000	82.320	1.6000e+05

Table based on one flow condition (P, T, Z, k ...) V40 Version 1.23
Standard Gas Expansion Equation - Rev. Aug. 2001

Record Start Date	02-28-2002
Print Date	02-25-2003

McCROMETER

V-Cone Application Sizing

Serial #	02-0535	Fluid State	GAS
Tag	02-FE-907A	Fluid	HC Gas
Model	VR24-03	End User	
Job Ref.	J89475		

Description	24" V-Cone, A672-B70 EFW Pipe, 1.25 WT, S316 Cone, A105 B16.5 900# WN RTJ Fl	Mktg. Code	3 6 030
Note			

C_f			
P_f	103.0	kg/cm2A	
T_f	65	°C	
ρ	79.78	kg/m3	
μ	1.200e-02	cP	⇐
G	0.6763		⇐
Z	0.8960		⇐
Y	0.99768		
k	1.520		⇐
C_p			
Mw	19.08		⇐
P_b	14.696	psiA	
T_b	491.67	°R	
Z_b	1.000		
P_{baro}	14.696	psiA	
P_c			
T_c			
F_a	1.001		
aPE	D 6.7e-06	d 6.7e-06	
P_v			
P_{loss}	1.702	psiA	

⇐ Entered value

q	max. Flowrate	1600000	Nm3/H
Re	max. Reynolds	7.528e+07	
V	max. Velocity	67.88	fps
ΔP	max. Dp	3970.2	mmWC
ΔP	min. Dp	39.518	mmWC
D	Meter I.D.	547.45	mm
d	Cone O.D.	329.31	mm
β	Beta Ratio	0.7988	
	Turn Down	10	

McCrometer Cal.	
Third Party Cal.	
Dye. Pen. Exam.	
Hydro. Test	
X-Ray Exam.	
Mag. Part.	
PMI	
CMTR Copies	
McCrometer Eng.	CG

	Re	Velocity fps	Gas. Exp. Y	ΔP mmWC	Flowrate Nm3/H
1	7.528e+07	67.883	0.9977	3970.2	1.6000e+06
2	6.776e+07	61.093	0.9981	3213.0	1.4400e+06
3	6.023e+07	54.307	0.9985	2536.6	1.2800e+06
4	5.270e+07	47.518	0.9989	1940.7	1.1200e+06
5	4.517e+07	40.730	0.9992	1425.0	9.6000e+05
6	3.764e+07	33.942	0.9994	989.06	8.0000e+05
7	3.011e+07	27.153	0.9996	632.73	6.4000e+05
8	2.259e+07	20.365	0.9998	355.79	4.8000e+05
9	1.506e+07	13.577	0.9999	158.08	3.2000e+05
10	7.528e+06	6.7883	1.0000	39.518	1.6000e+05

Table based on one flow condition (P, T, Z, k ...) V40 Version 1.23
Standard Gas Expansion Equation - Rev. Aug. 2001

Record Start Date	02-26-2002
Print Date	02-25-2003

McCROMETER

V-Cone Application Sizing

Serial #	02-0547	Fluid State	GAS
Tag	09-FE-907A	Fluid	HC Gas
Model	VR26-01	End User	
Job Ref	JB9475		

Description	28" V-Cone, A672-B70 EFW Pipe, 1.25 WT, S316 Cone, A105 B16.47A 900# WN RTJ	Mfdg. Code	3 8 030
Note			

C_f				q	max. Flowrate	2000000	Nm3/H	McCrometer Cal.	
P_f	104.9	kg/cm2A		Re	max. Reynolds	8.671e+07		Third Party Cal.	
T_f	65	°C		V	max. Velocity	71.40	fps	Dye. Pen. Exam.	
ρ	80.04	kg/m3		ΔP	max. Dp	4391.7	mmWC	Hydro. Test	
μ	1.200e-02	cP	=	ΔP	min. Dp	43.896	mmWC	X-Ray Exam.	
G	0.6798		=	D	Meter I.D.	597.26	mm	Mag. Part.	
Z	0.9000		=	d	Cone O.D.	358.14	mm	PMI	
Y	0.99744			β	Beta Ratio	0.8003		CMTR Copies	
κ	1.530		=		Turn Down	10		McCrometer Eng.	CG
C_p									
Mw	19.69		=						
P_b	14.696	psiA							
T_b	491.67	°R							
Z_b	1.000								
P_{baro}	14.696	psiA							
P_c									
T_c									
F_a	1.001								
±PE	D 6.7e-06	d 6.7e-06							
P_v									
P_{loss}	1.572	psiA							

= Entered value.

	Re	Velocity fps	Gas. Exp. Y	ΔP mmWC	Flowrate Nm3/H
1	8.671e+07	71.405	0.9974	4391.7	2.0000e+06
2	7.804e+07	64.264	0.9979	3553.8	1.8000e+06
3	6.937e+07	57.124	0.9984	2805.4	1.6000e+06
4	6.069e+07	49.983	0.9988	2145.3	1.4000e+06
5	5.202e+07	42.843	0.9991	1575.8	1.2000e+06
6	4.335e+07	35.702	0.9994	1093.7	1.0000e+06
7	3.468e+07	28.562	0.9996	699.67	8.0000e+05
8	2.601e+07	21.421	0.9998	393.41	6.0000e+05
9	1.734e+07	14.281	0.9999	174.81	4.0000e+05
10	8.671e+06	7.1405	1.0000	43.896	2.0000e+05

Table based on one flow condition (P, T, Z, κ ...) V40 Version 1.23
Standard Gas Expansion Equation - Rev. Aug. 2001

Record Start Date	02-28-2002
Print Date	02-25-2003

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V-Cone Application Sizing

Serial #	02-0538	Fluid State	GAS
Tag	02-FE-909A	Fluid	HC Gas
Model	VR28-01	End User	
Job Ref.	J89475		

Description	28" V-Cone, A672-B70 EFW Pipe, 1.25 WT, 316 Cone, A105 B16.47A 900# WN RTJ	Mktg. Code	3 6 030
Note			

C_T				q	max. Flowrate	1600000	Nm3/H	McCrometer Cal.	
P_f	78.2	kg/cm2A		Re	max. Reynolds	6.883e+07		Third Party Cal.	
T_f	55	°C		V	max. Velocity	79.14	fps	Dye. Pen. Exam.	
ρ	57.20	kg/m3		ΔP	max. Dp	3942.0	mmWC	Hydro. Test	
μ	1.200e-02	cP	⇐	ΔP	min. Dp	39.160	mmWC	X-Ray Exam.	
G	0.6763		⇐	D	Meter I.D.	598.65	mm	Mag. Part.	
Z	0.9100		⇐	d	Cone O.D.	360.20	mm	PMI	
Y	0.99667			β	Beta Ratio	0.7988		CMTR Copies	
k	1.450		⇐		Turn Down	10		McCrometer Eng.	CG
C_P									
Mw	15.58		⇐						
P_b	14.696	psiA							
T_b	491.67	°R							
Z_b	1.000								
P_{baro}	14.696	psiA							
P_D									
T_R									
F_a	1.001								
aPE	D 6.7e-06	d 6.7e-06							
P_v									
P_{loss}	1.091	psiA							

⇐ Entered value.

	Re	Velocity fps	Gas. Exp. Y	ΔP mmWC	Flowrate Nm3/H
1	6.883e+07	79.136	0.9967	3942.0	1.6000e+06
2	6.195e+07	71.222	0.9973	3188.9	1.4400e+06
3	5.507e+07	63.308	0.9979	2518.8	1.2800e+06
4	4.818e+07	55.395	0.9984	1925.0	1.1200e+06
5	4.130e+07	47.481	0.9988	1413.1	9.6000e+05
6	3.442e+07	39.568	0.9992	980.56	8.0000e+05
7	2.753e+07	31.654	0.9995	627.21	6.4000e+05
8	2.065e+07	23.741	0.9997	352.83	4.8000e+05
9	1.377e+07	15.827	0.9999	156.67	3.2000e+05
10	6.884e+06	7.9136	1.0000	39.160	1.6000e+05

Table based on one flow condition (P, T, Z, k ...) V40 Version 1.23
Standard Gas Expansion Equation - Rev. Aug. 2001

Record Start Date	02-28-2002
Print Date	02-25-2003

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V-Cone Application Sizing

Serial #	02-0552	Fluid State	GAS
Tag	09-FE-809A	Fluid	HC Gas
Model	VR20-01	End User	
Job Ref.	J89475		

Description	28" V-Cone, A672-B70 EFW Pipe, 1.25 WT, 5316 Cone, A105 B16.47A 900# WN RTJ	Mktg. Code	3.6 000
Note			

C_f				q	max. Flowrate	2000000	Nm3/H		McCrometer Cal.	
P_f	76.1	kg/cm2A		Re	max. Reynolds	7.975e+07			Third Party Cal.	
T_f	55	°C		V	max. Velocity	83.27	fps		Sys. Pen. Exam.	
ρ	58.67	kg/m3		ΔP	max. Dp	4341.9	mmWC		Hydro. Test	
μ	1.200e-02	cP	=	ΔP	min. Dp	43.104	mmWC		X-Ray Exam.	
G	0.6798		=	D	Meter I.D.	649.35	mm		Mag. Part.	
Z	0.9600		=	d	Cone O.D.	390.83	mm		PMI	
Y	0.99633			β	Beta Ratio	0.7988			CMTR Copies	
k	1.450		=		Turn Down	10			McCrometer Eng.	GG
C_p										
Mw	19.68		=							
P_b	14.696	psiA								
T_b	491.67	°R								
Z_b	1.000									
P_{baro}	14.696	psiA								
P_c										
T_c										
F_a	1.001									
aPE	D 6.7e-06	d 6.7e-06								
P_v										
P_{loss}	1.984	psiA								

= Entered value.

	Re	Velocity fps	Gas. Exp. Y	ΔP mmWC	Flowrate Nm3/H
1	7.975e+07	83.268	0.9963	4341.9	2.0000e+06
2	7.177e+07	74.942	0.9970	3512.0	1.8000e+06
3	6.380e+07	66.615	0.9977	2771.4	1.6000e+06
4	5.582e+07	58.288	0.9982	2119.8	1.4000e+06
5	4.785e+07	49.961	0.9987	1555.7	1.2000e+06
6	3.987e+07	41.634	0.9991	1079.5	1.0000e+06
7	3.190e+07	33.307	0.9994	690.39	8.0000e+05
8	2.392e+07	24.981	0.9997	388.16	6.0000e+05
9	1.595e+07	16.654	0.9999	172.46	4.0000e+05
10	7.975e+06	8.3268	1.0000	43.104	2.0000e+05

Table based on one flow condition (P, T, Z, k ...) V40 Version 1.23
Standard Gas Expansion Equation - Rev. Aug. 2001

Record Start Date	02-28-2002
Print Date	02-26-2003

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